NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A COST ANALYSIS OF THE DECISION TO CANNIBALIZE MAJOR COMPONENTS OF THE NAVY'S H-60 HELICOPTERS AT THE OPERATIONAL LEVEL

by

Danny E. Kowalski

June 2000

Thesis Advisors: Donald Eaton
Shu S. Liao

Approved for Public release; Distribution is Unlimited

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
June 2000

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE : A COST ANALYSIS OF THE DECISION TO CANNIBALIZE MAJOR COMPONENTS OF THE NAVY'S H-60 HELICOPTERS AT THE OPERATIONAL LEVEL

5. FUNDING NUMBERS

6. AUTHOR(S)
Kowalski, Danny E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT Cannibalization is a technique, sanctioned by the Navy, for maintenance managers to optimize aircraft availability by circumventing a slow or inadequate logistics support system. Maintenance managers often make a decision to cannibalize without considering the total cost of their decision. This thesis examines the costs incurred by an operational H-60 helicopter squadron to cannibalize major components and addresses the impact of cannibalization on the mean time between failure for the cannibalized components. The costs to cannibalize a T700-GE-401C engine, a tail rotor blade and an auxiliary power electronic control unit were calculated by assigning a dollar value to the increased manpower, consumables and flight time that could have been avoided if cannibalization were not used. The units cannibalized in 1996 were tracked by serial number through 1999 to compare their mean time between failure to similar non-cannibalized units tracked for the same period. The findings were that cannibalization considerably decreases the time between failure for cannibalized components which can have far-reaching effects on the size and costs of the Navy's inventory of spare parts. The increased manpower, consumables and flight time required has a significant impact on an operational squadron's workforce and budget.

14. SUBJECT TERMS
Cannibalization, Aircraft Maintenance, Cost Analysis

15. NUMBER OF PAGES
88

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

A COST ANALYSIS OF THE DECISION TO CANNIBALIZE MAJOR COMPONENTS OF THE NAVY'S H-60 HELICOPTERS AT THE OPERATIONAL LEVEL

Danny E. Kowalski
Commander, United States Navy Reserve
M.B.A., University of Phoenix, 1996
B.S., United States Naval Academy, 1982

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 2000

Author: ______________________
Danny E. Kowalski

Approved By: ______________________
Donald Eaton, Thesis Advisor

____
Shu S. Liao, Thesis Advisor

______________________ for
Ruben T. Harris, Chairman
Department of Systems Management

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

A COST ANALYSIS OF THE DECISION TO CANNIBALIZE MAJOR COMPONENTS OF THE NAVY'S H-60 HELICOPTERS AT THE OPERATIONAL LEVEL

Cannibalization is a technique, sanctioned by the Navy, for maintenance managers to optimize aircraft availability by circumventing a slow or inadequate logistics support system. Maintenance managers often make a decision to cannibalize without considering the total cost of their decision. This thesis examines the costs incurred by an operational H-60 helicopter squadron to cannibalize major components and addresses the impact of cannibalization on the mean time between failure for the cannibalized components. The costs to cannibalize a T700-GE-401C engine, a tail rotor blade and an auxiliary power electronic control unit were calculated by assigning a dollar value to the increased manpower, consumables and flight time that could have been avoided if cannibalization were not used. The units cannibalized in 1996 were tracked by serial number through 1999 to compare their mean time between failure to similar non-cannibalized units tracked for the same period. The findings were that cannibalization considerably decreases the time between failure for cannibalized components which can have far-reaching effects on the size and costs of the Navy's inventory of spare parts. The increased manpower, consumables and flight time required has a significant impact on an operational squadron's workforce and budget.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to determine the total cost to a Navy operational H-60 Seahawk Helicopter Squadron when cannibalization is used as a technique to increase the aircraft mission readiness. By identifying and quantifying the total cost of cannibalization, squadron commanders will be able to make informed decisions to efficiently manage their resources. Specifically, this thesis will focus on the cannibalization practices involved with major components of the H-60. Archival maintenance records will be examined to calculate the additional man-hours required to cannibalize a major component from one aircraft for installation in another. A dollar value will be assigned to the man-hours incurred for the increased maintenance actions that would not have been required if the component was obtained through the regular Navy supply channels. Standard military pay equivalent charts will be used to assign a direct labor cost to the cannibalization action based on the number and pay grade of technicians involved.

This thesis will also determine if cannibalization results in an additional cost to the Navy through the degradation of the installed service life of a cannibalized component as compared to a component that remains installed in the same aircraft for its entire useful life. Three dissimilar high value H-60 components, frequently cannibalized over the past five years, will be analyzed to determine if a relationship exist between cannibalization and reduced installed useful life. Service life, maintenance and supply data will be obtained from Naval Aviation Logistics Data Analysis (NALDA) databases and reports. A base year will be selected to determine if a relationship exist between cannibalization and service life.

B. BACKGROUND

1. The H-60 Helicopter

The H-60 Seahawk is a twin-engine multipurpose helicopter, manufactured by the United Technologies Corporation, Sikorsky Aircraft Division. Its missions include anti-submarine warfare, search and rescue, drug interdiction, anti-ship warfare, cargo lift, and special operations. The Navy's SH-60B Seahawk is an airborne platform based aboard cruisers, destroyers, and frigates. The helicopter deploys sonobouys and torpedoes in an anti-submarine role and extends the range of the ship's radar capabilities. The Navy's SH-60F is carrier-based and deploys a dipping sonar. The SH-60B Light Airborne Multi-Purpose System (LAMPS) MK III Block II/multi-mission helicopter upgrade will provide the Navy with a multi-mission platform capable of conducting undersea and surface warfare for the next 20-25 years.

2. Cannibalization

Cannibalization in Naval Aviation refers to the practice of physically removing a fully functioning part or component from one aircraft for installation in place of a similar defective part or component in another aircraft. In an effort to ensure that the maximum possible number of aircraft are maintained in a fully mission capable status, maintenance managers frequently use cannibalization under the following two scenarios with little regard to the total cost incurred by their decision to cannibalize. First, cannibalization is used during high-tempo operations when systems fail and must be immediately repaired to avoid jeopardizing the mission. Second, when replacement parts are not readily available through the Navy's normal supply channels, maintenance managers will sacrifice one squadron aircraft so that its parts will be available to repair other squadron aircraft. This practice tends to further exacerbate the supply deficiencies by masking the true demand and urgency for spare parts. Through cannibalization, Squadron Commanders are able to circumvent a slow or inadequately stocked supply system and optimize the number of mission capable aircraft available to meet short-term mission requirements and achieve readiness-reporting goals.

Although cannibalization can be an effect tool for successfully achieving short-term mission goals, the long-term effects tend to be negative. The Navy clearly discourages dependence on cannibalization and advocates a reduction in its use. As stated in The Naval Aviation Maintenance Program OPNAVINST 4790.2:

> Cannibalization, with few exceptions, is a manifestation of a logistic or maintenance support system failure. Cannibalization has a tendency to adversely impact morale and worsen a non-mission capable supply or partial-mission capable supply situation which theoretically it is intended to overcome. One goal of logistics and maintenance operations should be the elimination of unnecessary cannibalization. However, when properly supervised, cannibalization is a viable management tool. Policies regarding its use should be flexible in nature. Simultaneously, it must be recognized that the broader objectives of asset management and system discipline are fundamental to cannibalization reduction.[Ref. 1: para. 12.1.11]

Cannibalization is normally reported as a rate, determined by the ratio of the number of cannibalization actions per 100 flight hours. Over the past five years the cannibalization rate for all Navy aircraft including the H60 helicopter have shown a slight increase. Table 1.1 lists cannibalization rates for all Navy aircraft and specifically the H-60 helicopter for FY95-FY99. As an aggregate, the Navy's airforce averaged a cannibalization rate of 8.82, while the H-60 averaged 6.58. [Ref. 2]

Table 1-1 also shows that total number of Navy aircraft decreased by 24 percent from FY95-FY99. The number of H-60 helicopters decreased 7.3 percent during the same period.

ACFT	CATEGORY	FY95	FY96	FY97	FY98	FY99	%CHANGE	AVE
ALL NAVY	# OF ACFT	2565.5	2283.2	2016.0	2055.4	1951.1	-24%	
ALL NAVY	CANN/ 100 FH	8.4	8.4	9.1	9.3	8.9		8.82
H-60	# OF ACFT	144.0	138.5	132.4	136.5	133.5	-7.3%	
H-60	CANN/ 100 FH	7.0	6.3	6.0	6.3	7.3		6.58

Source: NAMSO 4790.A7049-01 DTD 21 Oct 99

Table 1-1 Cannibalization Rates for Navy Aircraft and H-60 Helicopter

Even though the cannibalization rate per 100 flight hours remained relatively stable, the number of cannibalizations per aircraft increased as the result of the smaller inventory. Table 1-2 shows that even though the number of H-60 hours flown per year decreased by 13.9 percent the cannibalization rate increased by 4.3 percent while the direct maintenance man hour (DMMH) per flight hour increased by 34.8 percent. One probable explanation for the dramatic increase in DMMH is that the fewer remaining aircraft were burdened by more cannibalization. Each of the remaining aircraft incurred the additional DMMH and the wear and tear associated with the removal and reinstallation of aircraft components for cannibalization.

ACFT	CATEGORY	FY95	FY96	FY97	FY98	FY99	%CHANGE
H-60	TOT A/C HRS FLOWN	22406	21329	18324	20311	19277	13.9 DECREASE
H-60	CANN/100 FH	7.0	6.3	6.0	6.3	7.3	4.3 INCREASE
H-60	DMMH/FH	20.4	19.7	22.1	24.5	27.5	34.8 INCREASE

Source: NAMSO 4790.A7049-01 DTD 21 Oct 99

Table 1-2. Change in H-60 Annual Flight Hours, Cannibalization Rate and DMMH/FH for FY95-FY99

3. Costs Associated with Cannibalization

In order to maximize readiness and meet pressing mission requirement, Commanders often discount the following costs associated with cannibalization: (1). Increased direct labor cost. Cannibalization requires triple work. Maintenance technicians must first impair one aircraft to repair a second aircraft only to repair the first aircraft later when the replacement part is available from the supply system. Decision-makers often ignore the additional direct labor cost incurred by cannibalization. Military labor costs remain constant regardless of the number of hours Sailors work. Since labor is not funded by the squadron's operational budget, Commanders have no financial incentive to reduce manpower requirements. (2). Increased material costs through the reduced life cycles of cannibalized parts. Removing a major component from one aircraft and installing it in another reduces the total useful installed service life of the component. The amortized cost of the reduced life of the component is a hidden cost of cannibalization. Over the long run, the Navy must purchase additional spare parts and maintain a larger inventory of ready spares to off set the effects of reduced service life. (3). Increased use of consumables and breakage. Less significant costs of cannibalization are the increased use of consumables such as lubricants, oils and packing associated with the increased maintenance actions and the losses related to accidental breakage in handling.

C. RESEARCH QUESTIONS

This thesis focuses on the following research questions:

Primary: What are the total costs to cannibalize high value components on the H-60 helicopter?

Secondary:

(1) Why do squadrons cannibalize?

(2) Does cannibalization reduce the installed service life of the cannibalized component?

(3) What is the cost of the increased maintenance associated with cannibalization?

II. LITERATURE REVIEW

A. INTRODUCTION

This chapter provides insight into official policies and attitudes related to cannibalization and how these policies and attitudes effect cannibalization practices in operational fleet squadrons. It also explains how squadrons use cannibalization.

B. CANNIBALIZATION POLICY

The Naval Aviation Maintenance Program (NAMP) recognizes cannibalization as a viable short-term solution to overcome failures of a logistics or maintenance support system. In this light, cannibalization is sanctioned as a tool to be used under close supervision to help squadron commanders maintain the highest possible aircraft readiness. Squadron commanders are directed to develop local policies that allow flexibility while at the same time recognizing that cannibalization is no substitute for skillful asset, logistic, and support system management. Commanders are to ensure that Cannibalization actions are limited to those necessary to meet mission requirements and are not used simply to improve Full Mission Capability statistics.[Ref. 3]

The NAMP also addresses the negative effects of cannibalization and recognizes the practice's adverse impact on the morale of the technicians whose workload is increased and the long term increased strain on the logistics support system. Rear Admiral David Keller, director of the Supply Programs and Policy Division for the Chief of Naval Operations, believes excessive cannibalization hurts personnel retention more than readiness but concedes that eventually the two issues are the same. In an interview with *Defense Week*, Rear Adm. Keller stated, "If we're driving people out because of spares shortfalls, we're exacerbating the problem." [Ref. 4] In a June 1999 survey on fleet perceptions of logistics support conducted by the Center for Naval Analyses at the request of the Assistant Deputy Chief of Naval Operations, dissatisfaction with logistics support among the aviation community was 39 percent, up from 5 percent five years ago. Cannibalization and excessive down time was one of the reasons most often mentioned for the decline in satisfaction [Ref. 5].

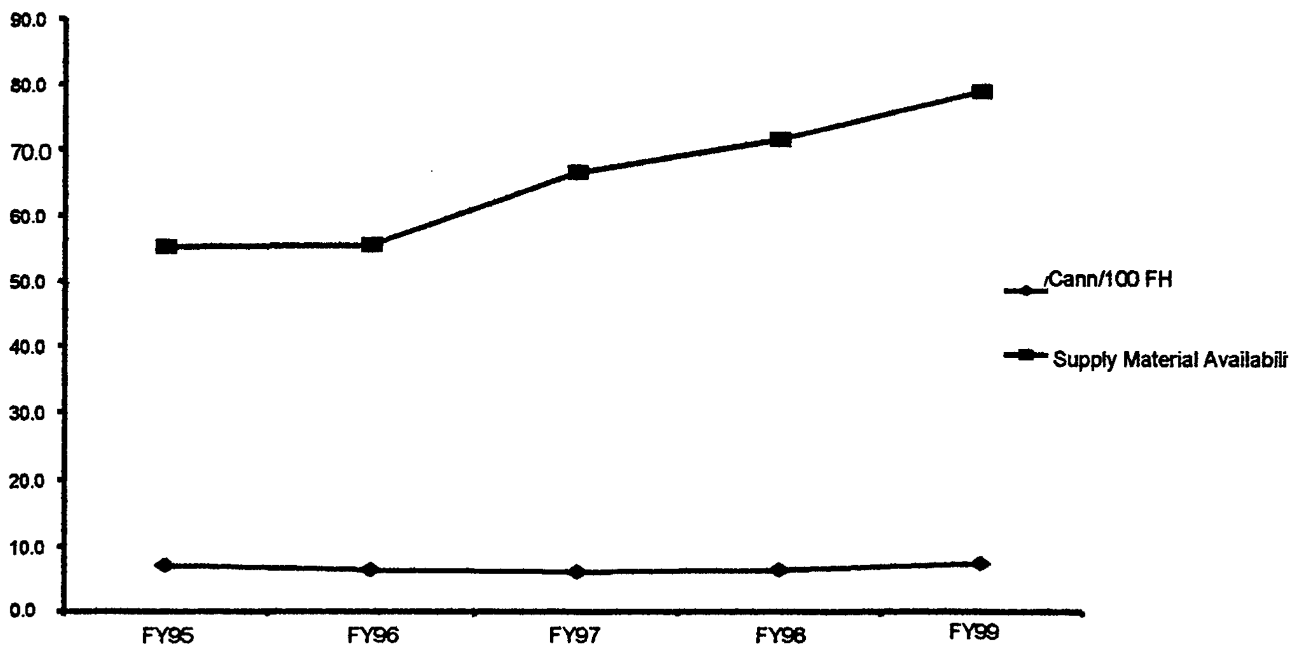
The Aircraft Inventory Reporting System (AIRS) instruction, OPNAVINST 5442.4, addresses the adverse effect of multiple cannibalizations on aircraft which have not flown for extended periods. The AIRS designates aircraft that have not flown for 60 consecutive days as Special Interest Aircraft (SPINTAC). Cannibalization is tightly controlled on SPINTAC because it is acknowledged that aircraft, which have had multiple cannibalizations, require an extraordinary effort to return to normal flying status. SPINTAC also alerts material and logistics managers to provide pointed assistance to help squadrons return the affected aircraft to flyable status as soon as possible.[Ref. 3]

In contrast to the Navy, the Airforce has explored cannibalization as a powerful management tool to help the logistics system to cope with the uncertainties in spare parts demand. In 1993 the Rand Institution published a study, *Estimating Aircraft Recoverable Spares Requirements with Cannibalization of Designated Items*, for the Airforce. Rand's research considered using cannibalization as a possible substitute for substantial capital investment required to maintain extensive inventories of spare parts. This study attempted to use a mathematical model to determine when cannibalization could be a cost-effective practice to reduce the investment in safety stock while maintaining a desired aircraft availability rate. By designating about 58 percent of all aircraft repairables as cannibalizable, based on ease of cannibalization and historic practice, the model demonstrated that the safety stock for the F-16 weapon system could be reduced by 30% while maintaining a 83% readiness rate.[Ref. 6]

Although this model appears to be cost effective for the logistics and supply system, it fails to consider the cost of cannibalization at the operational unit level. The study did not consider the additional cost of manpower, the adverse effect of cannibalization on the service life of parts, the increase use of consumables and breakage, and the negative impact cannibalization has on the morale and retention of skilled technicians. The study also did not consider the increased potential and associated cost of maintenance error when technicians are under extreme pressure to meet the tightly controlled launch schedule under the harsh conditions of an operationally deployed aircraft carrier.

C. WHY SQUADRONS CANNIBALIZE

The most common reason given for cannibalization is that there is a shortage of spares available from the normal supply system. In this case, squadron level maintenance managers choose to cannibalize in order to compensate for the lack of logistic support from the supply system. However, since fiscal year 1995 supply material availability (SMA) has improved considerably, while cannibalizations per 100 flight hours have remained the same or have shown a slight increase [Ref. 4:p7]. Figure 2-1 shows the increase in SMA and cannibalization rate per 100 flight hours for the Navy's H-60 helicopter for FY95-FY99.



Source: Department of Defense Program Budget Decision 423 DTD 1 December 1999

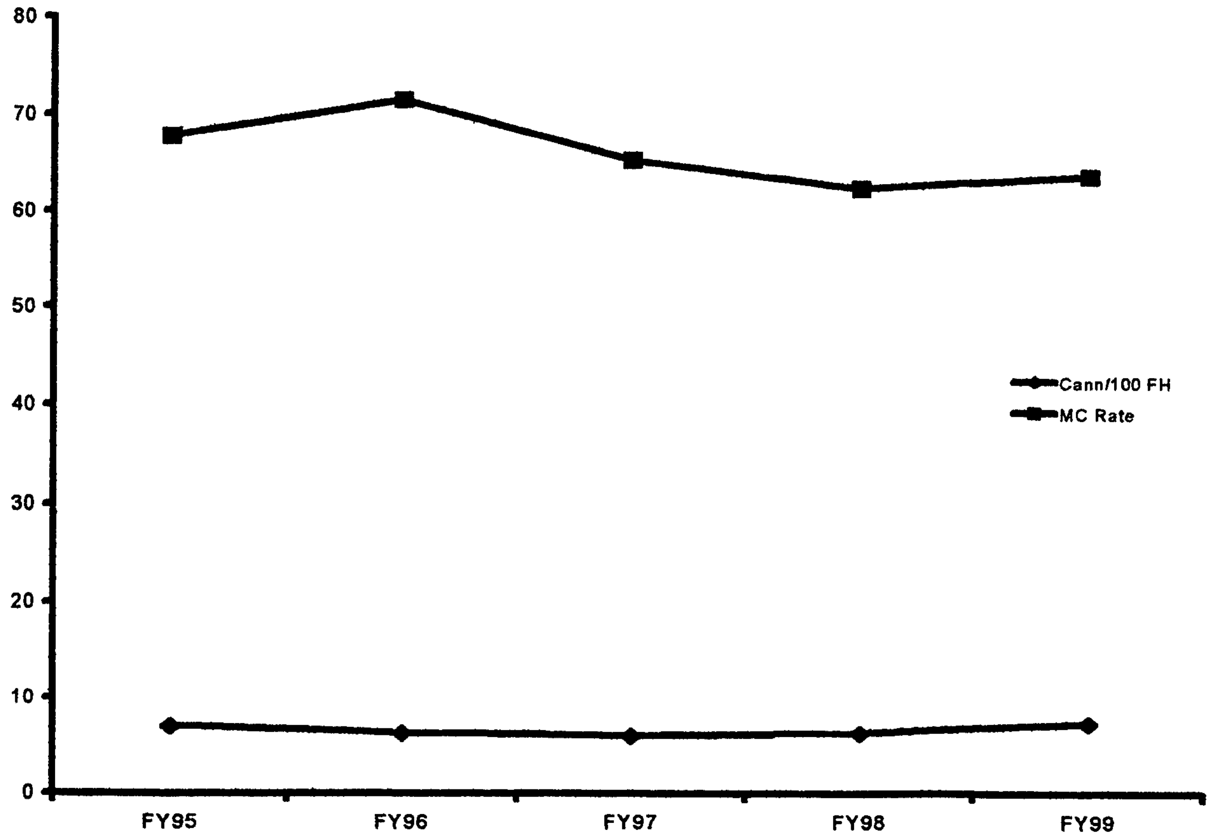
Figure 2-1. H-60 Cannibalizations per 100 Flight Fours and Percent Supply Material Availability

Based on the increase in SMA and the decrease in the number of H-60 helicopters in the fleet, it is reasonable to conclude that the number of cannibalizations should have declined instead of remaining relatively flat. A regression analysis of SMA (the independent variable) to cannibalizations per 100 flight hours, (the dependent variable) provides a t-statistic of .466 and a P value of .67. With a small sample size these values indicate that no relationship exist between cannibalization rate and SMA. Therefore, other factors presumably have a more significant influence in a squadron maintenance manager's decision to cannibalize.

Aircraft readiness statistics and supply response times are two additional factors that weigh heavily on maintenance managers' decision to cannibalize. Aircraft readiness is reported as a ratio of the number of hours an aircraft is mechanically capable of performing a mission to the number of hours available in a reporting period. The normal reporting period is one month. Most maintenance departments use aircraft readiness as a performance measure. Managers use cannibalization as a technique to improve readiness. By consolidating mission impacting discrepancies into one aircraft, managers are able to report a higher number of mission capable aircraft. Figure 2-2 shows a plot of mission capable rates and cannibalizations per 100 flight hours for the H-60 helicopter from FY95 – FY99. Despite the use of cannibalization, mission capable rates have declined as cannibalization rates have increased slightly.

A regression analysis of mission capable rates (dependant variable) and cannibalization per 100 flight hours (independent variable) provided a t-statistic of .227 and a P value of .227 indicating that there is no strong relationship between mission capable rates and cannibalization. One explanation for this anomaly is that fewer aircraft are flying more and longer flights. Cannibalizations can not occur on flying aircraft and aircraft that are flown regularly tend to have fewer problems. Additionally, many quick flight line cannibalizations impair the cannibalized aircraft for a relatively short period of time and have little impact or are not reported as negatively effecting readiness. Another explanation is that squadrons are adhering to the NAMP and are not using cannibalization as a method to boost readiness statistics.

Supply response time can have a major influence in the decision to cannibalize. During high-tempo operations, squadrons are under pressure to launch aircraft according to an intricately coordinated and timed flight plan.



Source: Department of Defense Program Budget Decision 423 DTD 1 December 1999

Figure 2-2. H-60 Cannibalization per 100 Flight Hours and Mission Capable Rates

When systems fail during operations maintenance managers often perceive that it is quicker to cannibalize than to wait for the supply system to respond, thereby reducing the possibility of jeopardizing the mission. To combat this perception the Navy has established maximum acceptable elapsed response times for the supply system to issue items available in the local supply stocks. Response time begins when the squadron's Material Control places a requirement on the supply system and ends when the requested material or its status is received at the requesting unit. Supply response time is a function of Issue Priority Group or Priority Designator. Table 2-1 shows the relationship among Issue Priority Group, Priority Designator and Processing Time.

Issue Priority Group	Priority Designator	Processing Time
1	1-2	1 Hour
2	4-8	2 Hours
3	9-15	24 Hours

Source: Naval Aviation Maintenance Program OPNAVINST 4790.2
Table 2-1 Supply Response Time

Issue Priority Group is assigned based on the impact of the requested part on the aircraft's readiness status. For example, requisitions for a part which causes an aircraft to be not mission capable is assigned as an Issue Priority Group 1. Priority Designator is assigned based on the criticality of the unit's mission. Most deployed peacetime squadrons are assigned a Priority Designator 3, shore based operational squadrons are generally assigned a Priority Designator 4.[Ref.1: para.18.4]

During high-tempo operations, maintenance mangers feel pressure to repair a mission degrading discrepancy in less than the hour it can expect to wait for supply to deliver the part. Two crews working simultaneously, one to remove the faulty part from the scheduled aircraft while the other impairs a non-flying aircraft, can at many times greatly expedite the repair by circumventing the supply chain. The scheduled aircraft can launch on its mission while the impaired aircraft waits for the logistics and supply system to produce the part. Although cannibalization may reduce elapsed clock time, the additional direct maintenance man-hours and administrative time greatly exceeds that which would have been required if the part was obtained through the supply system.

Cannibalization always requires twice the direct maintenance man-hours. In aviation where most actions require three technicians, (one to make the repair, a second to inspect the work and a third to make a quality control inspection for safety of flight repairs) cannibalization can greatly increase the direct man-hours and the workload of the squadron's maintenance technicians. In addition to direct maintenance man-hours, time spent in tool control and administrative documentation is also doubled. This increased administrative burden can lend itself to potential errors as workers focus on expediting the physical repair and preparing the aircraft for launch. During flight line cannibalization the is push is to get the aircraft in the air while allowing the paperwork to catch up once the aircraft is gone. This practice can result in poor quality control and potential aircraft safety of flight problems.

D. SUMMARY

The Navy sanctions cannibalization as a technique to help maintenance managers overcome short-term logistics failures to meet operational mission requirements. The Navy acknowledges the long-term negative effect of cannibalization on both morale and the normal logistic support system and discourages its use as a substitute for the normal supply system.

From FY95 though FY99 cannibalization for the H-60 helicopter has remained stable. SMA has increased while mission capability has decreased. Regression analysis indicated that there is no strong relationship between the number of cannibalizations and SMA or mission capable rates for the H-60 helicopter. Squadrons appear to abiding by the NAMP and using cannibalization only when necessary to meet critical mission requirements and not as a means merely to boost readiness statistics.

THIS PAGE INTENTIONALLY LEFT BLANK

III. DATA COLLECTION

A. INTRODUCTION

This chapter explains the plan and procedures used to gather and analyze the data to answer the research questions stated in Chapter 1. The research design is presented to explain the procedures used to ensure the validity and reliability of the data. The research design strategy describes the data used in this thesis and how the data was obtained and organized. It explains the how the data was analyzed and the sources of unit costs. The research instrument describes the database in detail and indicates the techniques employed to ensure the validity and reliability of the data.

B. RESEARCH DESIGN

This thesis addressed the total costs associated with using cannibalization at the organization level to increase the mission readiness of the Navy's H-60 helicopter. The author studied three dissimilar high value components that were frequently cannibalized by operational squadrons over the past five years.

To determine the total cost associated with cannibalization to an operational squadron, the author calculated the cost of the additional manpower, flight time and consumables used in cannibalization that would not have been required if the component was obtained through the normal supply system. Additionally, the service life of cannibalized components was compared to non-cannibalized components to determine if a relationship exist between cannibalization and reduced service life of components. The costs associated with reduced service life are potentially significant, far reaching. Calculation of these costs are beyond the scope of this thesis.

The primary data source used in this thesis was archival data compiled and maintained by the Naval Air Systems Command. The author accessed the Naval Air Logistics Data Analysis (NALDA) databases and reports via a computer internet connection. NALDA databases are compiled from the raw data collected from various source documents such as the Navy's 3-M system, squadron flight files and the Naval Air Logistics Command Management Information System (NALCOMIS).

As a secondary source of data, the author contacted Helicopter Anti-Submarine Wing Light Pacific, Helicopter Anti-Submarine Wing Pacific and Helicopter Wing Reserve in San Diego, California to verify that the NALDA database fairly represented the actual cannibalization experiences of the fleet.

The military equivalent manpower hourly wage rates used in this thesis were obtained from the Office of the Under Secretary of Defense (Comptroller) Reimbursable Rates tab K-3.[Ref. 7] Table 3-1 Summarizes the rates for Naval Personnel.

Pay Grade	Billable Annual Rate $	Hourly Rate $
O-3	91,200	50.16
E-7	67,625	37.19
E-6	58,675	32.27
E-5	50,100	27.55
E-4	41,225	22.67
E-3	34,250	18.37

Source: USD Comptroller

Table 3-1: Military Reimbursement Rates

Labor cost per cannibalization action was calculated using equation 3-1 below.

$$\textbf{Labor Cost} = \textbf{(Hours x Pay Grade1)+(Hours x Pay Grade2)}$$

In the case of the T700-GE-401C engine, actual labor costs were derived from LDMSS engine data displayed in Table 3-2.

T700-GE-401C 1997-1999			
Engines Removed			1,063
Flight Hours			721,666
Flight Hours per Removal			678.9
	Total	**ML-1 (I-Level)**	**ML-2 (O-Level)**
Labor Hours	141,035	18,319	122,715
Labor Cost	$7,198,544	$1,272,488	$5,926,056
Cost per Hour	$50.04	$69.46	$48.29

Source: LMDSS ad hoc report

Table 3-2: Hourly Labor Cost for T700-GE-401C Engine 1997-1999

In addition to direct labor costs, the cannibalization of components that are directly related to safety of flight require a post maintenance functional check flight prior to assigning the aircraft to an operational or training mission. The cannibalization of an engine or tail rotor blade requires a post maintenance functional check flight. The typical check flight requires 1.4 flight hours. Table 3-3 contains the average cost per flight hour of all H-60 types/models/series.

FY95	FY96	FY97	FY98	FY99	AVERAGE ALL YEARS
$1383	$1615	$1189	$1126	$1232	$1309

Source: LMDSS Budget Analysis (OP-20 Report FY95-FY99)

Table 3-3: Annual Average Cost per Flight Hour H-60 Helicopter

Component maintenance data was obtained from the NALDA Equipment Condition Analysis System report number 520. This report is a user designed ad hoc report that generates a list of the individual maintenance actions performed on a particular component by either part number or serial number entered by the user.

Consumables used in the removal and replacement of components were determined by consulting the appropriate Maintenance Instruction Manual. The actual costs of the consumables used in cannibalization were obtained from the Navy's Visibility and Management of Operations and Support Cost (VAMOSC) databases. The Federal Logistic Data (FEDLOG) was used to determine the current price of consumables not tracked by VAMOSC.

C. RESEARCH DESIGN STRATEGY

The top three high value components cannibalized where determined by examining Naval Aviation 3-M data for FY95 – FY99. To ensure that the selected component's installation and service life history were available, only components tracked by a Maintenance Record Card (MRC) were considered for this thesis. The three MRC tracked components with the highest cannibalization rate per 100 flight hours were identified as the tail rotor blade (2.566 cannibalizations per 100 flight hours), the T700-GE-401C turbo shaft engine (1.361 cannibalizations per 100 flight hours), and the auxiliary power electronic control unit (.899 cannibalizations per 100 flight hours). [Ref. 8]

The author used 1996 as a base year and then followed the maintenance history of individual components by serial number through 1999 to derive a comparison between cannibalization and reduced time between failure of the selected components.

D. RESEARCH LIMITATIONS

The primary limitation of this study is the inadequacy of data and incomplete reporting by operational squadrons. This limitation is highlighted in the following excerpt from the Aviation Maintenance and Supply Readiness Cannibalization Issue number 62:

> There appears to be significant differences in reporting engine cannibalizations between AV-3M, which compiles from Engine Transaction Reports (ERTs) and AEMS. The AV-3M system shows a mild picture of the cannibalization issues with a slight problem in the 4th quarter of FY97. AMES system shows a significant increase in cannibalizations in the 2nd quarter of FY97, that has remained at an average of 25 engine assembly cannibalizations per quarter.[Ref. 9]

NALDA databases are compiled from data submitted by several operational units dispersed throughout the world. The reliability of NALDA databases is dependent on the accuracy and completeness of the data collected and entered by the various units. Although aircraft engine data is well organized and easily accessed, other aircraft components are not tracked in detail.

This thesis was limited to examining the cost of the top three components with a MRC. Detailed data required for this thesis is collected and maintained only on major components tracked with a MRC. Although cannibalizations of these major components are frequent and have a longer negative impact on aircraft readiness, the majority of cannibalizations that occur at the organizational level are for minor components whose installed service life is not tracked in detail. The top three cannibalized items for the SH-60B for FY1995-FY1999 were the stabilizer actuator, tail rotor coupling and UHF antenna [Ref. 7]. Detailed information on those components is not maintained in an accessible database.

Incidental costs associated with cannibalization were not included in this thesis. The increased maintenance actions required by cannibalization results in a corresponding increase in waste due to breakage and packaging. Parts damaged in handling are not reported as cannibalizations and therefore were not considered in this thesis. The cost associated with aircraft mishaps associated with poor quality control when cannibalization is used during high tempo operations to get aircraft in the air is beyond the scope of this thesis. The cost to the Navy of reduced mean time between failure in additional spares and inventory can be significant. Calculation of this cost is dependant on many variables and is beyond the scope of this thesis.

The findings in this thesis are applicable only to the Navy's H-60 helicopter. Every military aircraft model has both unique supply support and maintenance requirements. The availability of replacement parts, the dynamic life of parts and the man-hours required to repair and replace aircraft parts vary among aircraft models.

IV. DATA PRESENTATION AND ANALYSIS

A. INTRODUCTION

This chapter presents the data obtained through the data collection methods described in Chapter III. Archival maintenance data for the Navy's H-60 helicopter's T700-GE-401C turbo shaft engine, tail rotor blade and auxiliary power electronic control unit was extracted from NALDA databases. Aviation 3-M reports were used to determine manpower requirements to cannibalize each of the three components studied. The cost that an operational unit incurs when it chooses to cannibalize was calculated based on the additional manpower, flight time and consumables required.

To illustrate the relationship between cannibalization and component service life, 1996 was selected as the base year for comparison. To determine if cannibalized components have a reduced time between failure, the author collected data on every T700-GE-401C engine, H-60 tail rotor blade and auxiliary power electronic control unit that received organizational maintenance or was cannibalized in 1996. Each component was tracked by its discreet serial number through 1999 to determine if subsequent maintenance was required. Each of the three components addressed in this thesis experienced a higher failure rate and decreased time between failures for cannibalized units as compared to similar components that were not cannibalized. A summary of the data obtained for each component follows.

B. TIME BETWEEN FAILURE AND FAILURE RATE COMPARISON

1. T700-GE-401C Turbo Shaft Engine

In 1996, the Navy's operational H-60 helicopter squadrons performed non-scheduled maintenance on 161 T700-GE-401C engines. Twenty-nine of the 161 engines serviced were cannibalized from one aircraft for installation in another aircraft. To effect a comparison between cannibalized and non-cannibalized engines, each of the 161 engines was tracked via its discreet serial number through 1999 to determine if and when additional unscheduled maintenance (considered component failure for this thesis) was required. The raw data is displayed in Appendix A.

The 29 units cannibalized at the organizational maintenance level experienced a 34 percent subsequent failure rate compared to 17 percent for both the non-cannibalized and the total population. The mean time between failure for cannibalized units was 721 hours as compared to 1336 hours for non-cannibalized units. This comparison is displayed in Table 4-1.

T700GE401C ENGINE 1996-1999			
	Total Units	Cannibalized Units	Non-Cannibalized
1996 O-Level Maintenance	161	29	132
Number of Failures 1996-1999	27	10	17
Failure Rate	17%	34%	17%
Mean Time Between Failure		721 hrs	1336 hrs

Table 4-1. Failure Rates and Times Comparison Between Cannibalized and Non-cannibalized T700GE401C Engines

An analysis of variance (ANOVA) was performed to determine if the difference in the mean time between failure of cannibalized and non-cannibalized units is statistically significant. The ANOVA revealed the mean time between failure for cannibalized engines to be 721hours with a standard deviation of 387.9. For non-cannibalized engines the mean is 1336 hours with a standard deviation of 1196.7. The ANOVA f-factor is 2.45 and the p-value 0.13 indicating that the difference in mean time between failure for the two groups is significant at the 87 percent confidence level.

2. Tail Rotor Blades

The Navy's H-60 helicopter squadrons performed unscheduled maintenance on 233 tail rotor blades in 1996. Of these 233 blades, 37 were cannibalized. Using the same technique used for T700-GE-401C engines, the failure rate and mean time between failure for cannibalized and non-cannibalized was determined. The raw data is displayed in Appendix B. The failure rate for cannibalized tail rotor blades was 59 percent compared to 24 percent for non-cannibalized units and 30 percent for the total population. The mean time between failure for cannibalized tail rotor blades was 775 hours compared to 1365 hours for non-cannibalized units. Table 4-2 illustrates this comparison.

Tail Rotor Blades 1996-1999			
	Total Units	Cannibalized Units	Non-Cannibalized
1996 O-Level Maintenance	233	37	196
Number of Failures 1996-1999	70	22	48
Failure Rate	30%	59%	24%
Mean Time Between Failure		775 hrs	1365 hrs

Table 4-2. Failure Rates and Times Comparison Between Cannibalized and Non-cannibalized H-60 Tail Rotor blades

An ANOVA was performed to determine if the difference in the mean time between failure of cannibalized and non-cannibalized units is statistically significant. The

ANOVA revealed the mean time between failure for cannibalized units to be 775 hours with a standard deviation of 881. The mean time between failure for non-cannibalized units is 1365 hours with a standard deviation of 1238. The ANOVA f-factor is 4.02 and the p-value 0.049 indicating that the difference in mean time between failure for the two groups is significant at a confidence level greater than 95 percent.

3. Auxiliary Power Electronic Control Unit

Finally, auxiliary power electronic control units were studied using the same techniques as above. Similar comparisons were derived. Sixty-one units received organizational maintenance in 1996. Sixteen of the 61 units were cannibalized. The subsequent failure rate for cannibalized units was 50 percent compared to 17 percent for non-cannibalized units and 26 percent for the total population. The raw data is displayed in Appendix C. The mean time between failure for cannibalized units was 775 hours compared to 1864 hours for non-cannibalized units. Table 4-3 summarizes the comparison.

Auxiliary Power Electronic Control Unit 1996-1999			
	Total Units	**Cannibalized Units**	**Non-Cannibalized**
1996 O-Level Maintenance	**61**	**16**	**45**
Number of Failures 1996-1999	**16**	**8**	**8**
Failure Rate	**26%**	**50%**	**17%**
Mean Time Between Failure		**705 hrs**	**1864 hrs**

Table 4-3. Failure Rates and Time Comparison Between Cannibalized and Non-Cannibalized H-60 Auxiliary Power Electronic Control Units

An ANOVA was performed to determine if the difference in the mean time between failure of cannibalized and non-cannibalized units is statistically significant. The ANOVA revealed the mean time between failure for cannibalized units to be 705 hours with a standard deviation of 489. The mean time between failure for non-cannibalized units is 1864 hours with a standard deviation of 1430. The ANOVA f-factor is 4.71 and the p-value 0.048 indicating that the difference in mean time between failure for the two groups is significant at confidence level greater than 95 percent.

The above comparisons of three dissimilar H-60 components indicate that cannibalization has a negative effect on the reliability and service life of aircraft parts. Because cannibalization increases failure rates and decreases the time between failures, a squadron's decision to cannibalize has far-reaching financial implications for the Navy.

The Navy Inventory Control Point (NAVICP) uses a maintenance replacement factor (MRF) in determining the optimal number of spare parts to purchase and maintain in inventory in order to support a desired readiness rate for each aircraft model at its particular location.

The MRF is comprised of the number of units found to be beyond the capability of maintenance (BCM) at the local Aircraft Intermediate Maintenance Department (AIMD) divided by the mean time before failure (MTBF) [Ref. 10]. Equation 4-1 below refers.

$$MRF = IBCM / MTBF$$

A decrease in MTBF as the result of cannibalization yields a corresponding increase in MRF. In response to the higher MRF, NAVICP must incur the additional costs of both purchasing additional spares and maintaining the larger inventory if it is to support the same readiness rates. An alternative to purchasing spare would be to invest in the local AIMD to expand its maintenance capabilities. The calculation of a dollar value for the increased support costs to NAVICP and the various AIMDs associated with cannibalization is beyond the scope of this thesis. The costs incurred at the squadron level to cannibalize each of the three components selected for this study are calculated below.

C. ORGANIZATIONAL COST ASSOCIATED WITH MAJOR COMPONENT CANNIBALIZATION

1. T700-GE-401C Turbo Shaft Engine

The maintenance and repairs for the T700-GE-401C turbo shaft engine is well documented in NALDA databases. For the five year period addressed in this thesis, The Navy cannibalized 134 engines from the H-60 helicopter at the organizational level. A list of these engines was extracted from the NALDA equipment condition analysis database and is displayed in Appendix D.

The costs incurred by an organizational unit when it chooses to cannibalize a T700-GE-401C engine in lieu of waiting and installing an engine received through the supply system are: (1) The additional manpower cost required for the maintenance department to remove a fully functional engine from one aircraft and then later replace it with an engine received from supply, (2) The cost of the flight time required to perform an in-flight functional check of the aircraft impaired by cannibalization once an engine is received from supply, (3) The labor cost for the flight crews and ground crews to perform the functional checks, and (4) The cost of consumable items used during the process.

Manpower required to remove and replace an engine on the H-60 helicopter averaged 11.1 man-hours per procedure. Based on the hourly wage rate of $48.42 for the T700-GE-401C engine displayed in Table 3-2, the incremental labor cost to cannibalize was calculated below.

Labor Cost = (11.1hr x $48.42)

Labor Cost = $535.46

The T700-GE-401C is a critical component for safety of flight; therefore an in-flight post maintenance functional check of the engine and its systems is required before the aircraft can be assigned to a mission. The typical function check flight requires 1.4 flight hours, a crew of two pilots and one system operator, and a two-person ground crew.

The cost of the additional flight time incurred from the decision to cannibalize is calculated by multiplying the average cost per flight hour, listed in Table 3-3 as $1309, by the required flying time of the in-flight check.

Flying Time cost = $1309 x 1.4 hours

Flying Time Cost = $1832.60

Flight crew costs are determined by the wage rates of the flight crew and the total time required to complete the check flight and related task. The typical check flight crew is composed of two pilots (normally O-3s) and a system operator (typically an E-5). The customary time allotted by the H-60 community for preflight activities is two hours. An additional thirty minutes are assigned for post flight duties. The additional flight crew costs incurred by the decision to cannibalize are computed below.

Flight Crew Cost = (Flying Time + Preflight Time + Post Flight Time) x 2(0-3 Hourly Rate) + E-5 Rate

Flight Crew Cost = (1.4hrs + 2hrs + .5hrs) x 2($50.16) + $27.55

Flight Crew Cost = $418.80

Each shore based helicopter flight requires a ground crew consisting of a least two persons to assist and direct the flight crew during launch and recovery. One hour is allotted for two ground crew personnel one E-4 and one E-3 to perform ground crew duties for each flight. The cost of the ground crew is calculated below.

Ground Crew Cost = ($22.67) x 1hr +18.37 x 1hr

Ground Crew Cost = $41.04

A list of consumables used to remove and replace a T700-GE-401C engine was obtained from the H-60 power plants organizational maintenance instructions manual and is displayed in Table 4-4.

Specification/Part Number	Nomenclature	Cost
AN960-416	Washer	$.10
AN960C516	Washer	$2.36
ANC516L	Washer	$2.19

AN960C616	Washer	$2.19
AN960C616L	Washer	$4.51
AN960C816	Washer	$5.30
MIL-A-907	Anti-seize Thread Compound	$2.96
MIL-L-23699	Lubricating Oil (8 qrts.)	$69.60
MIL-C-5501	Protective Caps and Plugs	$3.86
MS20002C5	Washer	$4.95
MS20002C6	Washer	$5.52
MS21043-4	Nut (Self Locking)	$17.57
MS24665-153	Cotter Pin (4)	$.80
MS24665-302	Cotter Pin (3)	$.24
MS3367-2-9	Tie Down Strap (Electric)	$2.27
MS9724-09	Bolt	$3.27
P-C-451	Abrasive Cloth	$1.01
P-C-458	Crocus Cloth	$1.83
P-D-680, Type III	Solvent	$9.35

Table 4-4. T700-GE-401C Consumables

The total cost of consumables used per engine change is $139.88.

The decision to cannibalize cost the operational unit $2967.78 per engine. For the five years 1994-1999 the Navy's operational units incurred an additional cost of $397,682 to cannibalize 134 T700-GE-401C engines.

2. Tail Rotor Blade

Maintenance and life cycle data for helicopter tail rotor blades are not as well documented as the T700-GE-402C turbo shaft engine. For the five year period addressed in this thesis, the Navy cannibalized 264 tail rotor blades from the H-60 helicopter at the organizational level. Data on these tail rotor blades were extracted from the NALDA equipment condition analysis database and is displayed in Appendix E.

The manpower required to remove and replace a tail rotor blade on the H-60 helicopter averaged 12.0 man-hours per procedure. The author assumed a manpower allocation rate of 20 percent for supervision and inspection and 80 percent for direct labor. The supervisor rate was charged at the average of the E7 and E-6 rate. The remaining 80 percent were assigned the E-5 rate for direct labor. Based on these assumptions and using the labor rates shown in Table 3-1, the additional labor cost incurred to cannibalize a tail rotor blade was calculated as follow:

$$\text{Labor Cost} = (12\text{hr} \times 20\% \times \$34.73/\text{hr}) + (12\text{hr} \times 80\% \times \$27.55/\text{hr})$$

$$\text{Labor Cost} = \$347.83$$

Like the engine, tail rotor blades are critical to safe flight and require a post maintenance in-flight functional check before the aircraft can be used for squadron missions. The cost associated with the check flight are the same as those for the engine, $1832.60 for flight time, $418.80 for flight crew, and $41.05 for ground crew.

A list of consumables used to remove and replace a rotor blade was obtained from the H-60 airframes organizational maintenance instructions manual and is displayed in Table 4-5.

Specification/Part Number	Nomenclature	Cost
CCC-C-440	Cheesecloth	$.90
MIL-C-5501	Protective caps	$3.60
MIL-C-85043	Low Lint Cloth	$1.25
MIL-C-85285	High Solids Polyurthane Coating	$17.55
MIL-S-8784	Sealing Compound	$3.50
MIL-S-8802, B-2	Sealing Compound	$11.56
MS20995NC32	Safety Wire	$1.86
MS28778-6	Packing	$.08
MS29512-07	Packing	$.11
VV-P-236	Petrolatum	$4.44

Table 4-5. Tail Rotor Blade Consumables

The total cost of consumables used per tail rotor blade change is $44.85.

The decision to cannibalize cost the operational units $2685.13 per blade. For the five years 1994-1999 the Navy's operational units incurred an additional cost of $708,874 to cannibalize 264 H60 tail rotor blades.

3. Auxiliary Power Electronic Control Unit

Similar tail rotor blades, the maintenance and life cycle data for auxiliary power electronic control units are not as well documented as the T700-GE-402C turbo shaft engine. For the five year period addressed in this thesis, the Navy cannibalized 65 auxiliary power electronic control units from the H-60 helicopter at the organizational level. Data on these auxiliary power electronic control units were extracted from the NALDA equipment condition analysis database and is displayed in Appendix F.

The manpower required to remove and replace an auxiliary power electronic control unit on the H-60 helicopter averaged 5.0 man-hours per procedure. Manpower was allocated as 20 percent at the average of E7 and E-6 rate for supervision and inspection. The remaining 80 percent were assigned theE-5 rate for direct labor. Based on these assumptions and using the labor rates shown in Table 3-1, the additional labor cost incurred to cannibalize a auxiliary power electronic control unit was calculated as follow:

Labor Cost = (5hr x 20% x \$34.73/hr) + (5hr x 80% x \$22.67/hr)

Labor Cost = \$125.41

The auxiliary power electronic control unit is not critical to the safety of flight; therefore an in-flight post maintenance check is not required. An operational check is performed on the ground as part of the installation procedure.

A list of consumables used to remove and replace an auxiliary power electronic control unit was obtained from the H-60 organizational maintenance instructions manual and is displayed in Table 4-6.

Specification/Part Number	Nomenclature	Cost
MIL-C-5501	Protective Caps and Plugs	\$3.86
MIL-G-21164	Grease	\$6.58
MS20995C32	Safety Wire	\$1.86
MS9135-01	Gasket	\$.06
169037-1 (55820)	Grommet Tube	\$128.31

Table 4-6. Auxiliary Power Electronic Control Unit Consumables

The total cost of consumables used per auxiliary power electronic control unit change is $44.85.

The decision to cannibalize cost the operational squadrons $170.26 per unit. For the five years 1994-1999 the Navy's operational units incurred an additional cost of $11,066.90 to cannibalize 65 auxiliary power electronic control units on the H60 helicopter.

D. SUMMARY

This chapter clearly illustrated the relationship between cannibalization and the decreased time between failures and the relationship between cannibalization and the higher rate of failure of major aircraft components. The three major components studied in this thesis experienced a substantial decrease in the time before failure for a cannibalized component as compared to a similar component that was not cannibalized. Similarly, cannibalized units experienced a higher re-failure rate as compared to non-cannibalized units. This chapter also reveals the direct cost to squadrons in terms of the additional manpower, consumables and flight time required to accomplish the redundant maintenance procedures that are an inherent part of cannibalization.

A Cannibalized T700-GE-401C engine required unscheduled maintenance 615 hours sooner than a similar non-cannibalized engine. In the time period of this study 34 percent of engines cannibalized in 1996 required unscheduled maintenance prior to the end of 1999 compared to 17 percent of engines that received other unscheduled maintenance in 1996. Cannibalized tail rotor blades failed 590 hours sooner and had a 59 percent failure rate as compared to a 25 percent failure rate for non-cannibalized blades. Finally, cannibalized auxiliary power electronic control units failed 1159 hours sooner and had a 50 percent failure rate as compared to 17 percent failure rate for non-cannibalized unit.

The decrease time between failure has a direct impact on the cost of supply support. NAVICP uses mean time between failure as a factor in determining how many spares are required to support a given readiness goal. As mean time between failure decreases, NAVICP must increase its inventory of spare part and bare the additional costs associated with larger inventories. Determining these costs is beyond the scope of this study.

Squadrons engender substantial cost when they decide to cannibalize. Notably, cannibalizing components that require an in-flight post maintenance functional check flight have a substantially higher cost to a squadron than those that do not require a check flight. The cost of consumables and additional flight time required for in-flight functional checks have a direct negative impact a squadron's operational budget. Although the additional manpower required to cannibalize is not directly funded by the operational unit, it does have a direct impact on the morale and retention of highly trained and skilled technicians.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

This chapter presents the conclusions derived from the data analysis presented in Chapter IV. The research questions are answered and the effects of the research limitations listed in Chapter III are discussed. Recommendations for using cannibalization and further study are provided.

B. CONCLUSIONS

1. Cannibalization is an Expensive Alternative to the Normal Supply System for Operational Squadrons to Obtain Spare Parts.

An analysis of the data presented in Chapter IV clearly indicates that cannibalization has a significant negative impact on the resources of an operation squadron. This study identified and quantified the high costs associated with cannibalization of three dissimilar aircraft components frequently cannibalized by the H-60 helicopter community, the T700-GE-701C turbo prop engine, H-60 tail rotor blade, and the auxiliary power electronic control unit. By assigning a fair market value to the redundant manpower, extra consumables used and flight time required, cannibalization added $2967.78 to the costs of replacing a T700-GE-401C engine, $2685.13 to a tail rotor Blade and $170.26 to the costs of a auxiliary power electronic control unit. For the five years 1995-1999, the Navy's H-60 squadrons spent a total of $1,117,622 to cannibalize the three components listed above.

2. Cannibalization Reduces the Mean Time Between Failure for Cannibalized Components as Compared to Similar Non-cannibalized Units.

The three components studied in this thesis illustrated a direct relationship between cannibalization and reduced time between failure. Cannibalized T700-GE-401C engines experienced both a higher failure rate and shorter time between failure than non-cannibalized engines. Of the 161 engines studied from 1996-1999, cannibalized engines reported a 34 percent failure rate and 721 hours between failure as compared to 17 percent failure rate and 1336 hours between failure for non-cannibalized engines. The historic mean time between failure for all T700-GE-401C engines as reported in the Aircraft Engine Management System is 1071.97 hours [Ref. 11].

Of the 233 tail rotor blades studied from 1996-1999, cannibalized blades experienced a 59 percent failure rate and 775 hours between failure compared to a 24 percent failure rate and 1365 hours between failure for non-cannibalized blades. The historic time between failure for all H-60 tail rotor blades is 1301 hours [Ref 11].

Auxiliary power electronic control units showed similar results for the 61 units studied from 1996-1999. The failure rate for cannibalized units was 50 percent with the time between failure of 705 hours compared to a 17 percent failure rate and 1864 hours between failure for non-cannibalized units. The historic time between failure for this component is 3014 hours and includes those units installed on Navy aircraft other than the H-60 helicopter [Ref. 11].

3. Cannibalization Has a Negative Impact on Organizations Outside of the Operational Unit.

Cannibalization imposes added costs to organizations outside of the operational unit by reducing the time between failure for cannibalized components as compared to similar component that were not cannibalized. For example, NAVICP uses meantime between failures as an input function to determine the size of inventory required for a particular part. A decrease in the time between failure of a component requires a larger inventory of spares. To support a constant readiness rate NAVICP must invest in and bear the related expenses of the larger inventory. Additionally, the higher turn over in repairables caused by decreased time between failures precipitates an increase in labor, consumables, and packing and shipping cost for Aircraft Intermediate Maintenance Departments (AIMD) and Aviation Depots.

4. Cannibalizing Items Requiring an In-flight Post Maintenance Functional Check Have a Greater Negative Impact on the Squadron's Resources Than Those That Do Not.

The additional flight time and manpower required as the result of cannibalization must be diverted from other priorities to the performance of the required in-flight checks. In the case of the H-60 helicopter, a typical post maintenance check flight added $2,292.44 in flight time and related labor to the costs of an aircraft repair when cannibalization was used for flight critical components.

B. RESEARCH QUESTIONS ANSWERED

1. What are the Total Costs to Cannibalize Major Components on The H-60 Helicopter?

The researcher identified three types of costs associated with cannibalization: 1) direct costs, 2) indirect costs and 3) intangible costs. Direct costs are those costs that directly impact the resources of the unit which decides to cannibalize. Indirect costs are those costs imposed on organizations outside of the cannibalizing unit. Intangible costs are those that go unreported or are indirectly the result of cannibalization.

a. *Direct Costs*

The direct costs of cannibalization are labor, consumables, and flight time. Direct labor increases with cannibalization in two ways. First maintenance technicians must impair one aircraft to repair a second only to repair the second aircraft later when the appropriate part is received from supply. This results in a redundant removal and replacement that would not have occurred if cannibalization were not used. Second, if the cannibalized component is considered critical to the airworthiness of the aircraft, a flight crew and supporting ground crew is required to perform an in-flight post maintenance check of the component and its related systems.

The costs of consumables are doubled as the result of the redundant maintenance actions. The removal and replacement of most major components requires preparation materials, non-reusable hardware and lubricants. The squadrons must divert funds from other priorities to pay for these items.

Cannibalizing components that are deemed critical to the safety of flight create the requirement to perform an in-flight post maintenance check flight on both the repaired aircraft and then later an additional flight on the aircraft that was impaired by cannibalization, once the required part is received from supply. The number of flight hours required for an in-flight check vary and can become burdensome if unexpected problems occur with the aircraft's systems. The flight hours to perform these flights are diverted from those hours allocated to the squadron to perform its required missions and training.

b. Indirect Costs

The indirect costs of cannibalization are those costs imposed upon organizations outside of the operational unit. These costs are manifested in the additional investments the supporting activities must make in their infrastructure and core competencies, due to the higher demand created by cannibalization, to continue to support the operational unit at a constant readiness level.

This thesis identified a direct relationship between cannibalization and a decrease in time mean between failure for cannibalized components. The size of NAVICP's inventory for a particular part is a function of that part's mean time between failure. As the time between failure decreases, NAVICP is forced to incur the cost of procuring and maintaining a larger standing inventory to compensate for the higher failure rate. The shorter installed life of cannibalized components also increases the work load and processing cost for AIMDs and aviation depots that are charged with repairing the failed parts. Indirect costs can be considerable. The current cost to purchase just one additional T700-GE401C engine is $619,079 [Ref. 11] while the specialized labor required to repair aircraft components commands an ample wage.

c. Intangible Cost

Intangible costs are those that arise after the cannibalization but are not planned or expected. These include the costs from breakage during handling, lost parts, work force injury, collateral damage to the aircraft during the maintenance procedure and possibly the loss of an aircraft and crew if short cuts are used to effect a quick repair. Intangible costs are not officially recorded or track as part of cannibalization, however they can be greatly increase the costs of cannibalization.

2. Why do Squadrons Cannibalize?

Cannibalization is a technique sanctioned by the Navy to help maintenance managers overcome short-term logistics failures to meet operational mission requirements. This thesis found that there is no relationship between supply material availability (SMA) and cannibalization rates. Cannibalization rates remained constant during both increases and decreases in SMA, indicating that commanders are using cannibalization only when necessary to increase short-term aircraft availability requirements.

3. Does Cannibalization Reduce the Installed Service Life of the Cannibalized Component?

This thesis clearly illustrated that cannibalized components on the H-60 helicopter have a shorter time between failure than similar components that were not cannibalized. Three dissimilar H-60 components, T700-GE-401C engine, H-60 tail rotor blade, and the auxiliary power electronic control unit, were studied to determine if cannibalized units experienced a shorter time between failure than similar non-cannibalized units within the same time frame. Each of the three components studied demonstrated a marked decrease in time between failure for the cannibalized unit as compared to a similar unit that was not cannibalized. Additionally, the cannibalized units experienced a higher failure rate than non-cannibalized units during the same period.

4. What is the Cost of the Increased Maintenance Associated with Cannibalization?

This thesis determined the direct costs of the increased maintenance to an operational H-60 helicopter squadron for three major components frequently cannibalized. The costs of the additional labor, consumables, and flight time to perform in-flight post maintenance checks were computed. The cost to cannibalize a T700-GE-401C engine is $2967.78 per unit, for a tail rotor blade the cost is $2685.13 and for an auxiliary power electronic control unit the cost is $170.26. The indirect costs and intangible costs resulting from cannibalization can substantially increase these costs, however calculation of these costs is beyond the scope of this thesis.

C. EFFECTS OF LIMITATIONS

This research was limited by the accuracy, completeness and consistency of the data extracted from the NALDA maintenance databases. Many components were missing complete maintenance histories, others where tracked by aircraft time for some maintenance actions and then component time for other actions. Units with incomplete or inconsistent data were excluded from the study.

The author defined 'failure' as any unscheduled maintenance when calculating mean time between failure and failure rate. In some cases the subsequent unscheduled maintenance required could have been minor repairs that had little impact on the continued operation of the component.

The study was limited to major components that are tracked by MRCs. This limitation prevented the researcher from capturing data on the many minor parts that are routinely cannibalized during flight operations. Of the top three items reported cannibalized, none are sufficiently tracked for inclusion in this study.

D. RECOMMENDATIONS

1. When Considering Cannibalization, Decision-makers Must Weigh the Expected Short-term Benefits in Terms of Aircraft Availability and Mission Readiness with the Total Cost of Cannibalization.

Cannibalization is an expensive technique to increase aircraft readiness statistics. Before deciding to cannibalize, maintenance managers should consider the impact of their decision on the unit's operational budget, the morale of their workforce and the far-reaching effects their decision has on the costs to peripheral support activities. They must be aware of that cannibalization can decrease the mean time between failure of major components. Shorter time between failure results in fewer spares available. This trend can lead to even more cannibalization, further exacerbating the problem it was intended to overcome and creating more serious aircraft maintenance and logistic systems short falls.

2. Cannibalization Must be a Closely Supervised Event Conducted with the Same Controls in Place as any Other Aircraft Repair Procedure.

When cannibalizing, the speed of the repair must be secondary to the quality and safety of the repair in order to minimize the possibility and amount of intangible costs. Unreported cost associated with cannibalization such as breakage and injuries to workers can substantially increase the cost of cannibalization. During high tempo operations the pressure to launch aircraft on schedule creates an atmosphere ripe for errors. The probability of damaging a component during handling greatly increases when it is removed from one aircraft and transported without the proper container. Under these conditions the possibility of loosing an aircraft and crew to maintenance error is more likely as short cuts in procedures and documentation are used to expedite repairs.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Research is Needed to Determine the Indirect and Intangible Costs of Cannibalization.

These costs can greatly increase the costs of cannibalization to both the Navy and the operational unit. Further study is needed to quantify these costs so that maintenance managers can appreciate the full impact of their decision to cannibalize on both the resources under their control and those of the organizations charged with supporting them.

Although this study focuses on the cost to cannibalize major components of the H-60 helicopter, it is possible that cannibalization of components in other aircraft types could have a similar negative impact on squadron resources and supporting activities.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. T700-GE-401C ENGINES THAT RECEIVED UNSCHEDULED MAINTENANCE IN 1996

	BUREAU NUMBER	SERIAL NUMBER	TIME at Maintenance	CANN Y/N	Time at FAILURE	TIME BEFORE FAILURE CANN	TIME BEFORE FALURE NON-CANN
1	163288	336000	1912	N			
2	164101	336149	2819	N			
3	164456	336489	2416	N			
4	164446	336514	2504	N			
5	164451	366010	1304	N			
6	164099	366013	4346	N			
7	162344	366019	3590	N			
8	163249	366021	3817	N			
9	163237	366048	1580	N			
10	164084	366054	3696	N			
11	163244	366055	1724	N			
12	164454	366058	2565	N			
13	164812	366066	3687	N	3980		293
14	164071	366067	3794	Y			
15	164074	366068	2386	N			
16	165259	366070	2155	N			
17	162115	366073	2083	N			
18	164447	366082	2477	N			
19	164455	366084	2462	Y			
20	162121	366086	2633	N			
21	162095	366095	2434	N	3887		1453
22	163784	366097	2556	Y			
23	163796	366100	2460	N			
24	164091	366110	3246	N			
25	163786	366111	2725	N			
26	162344	366112	2206	N			
27	366114	366114	4186	N			
28	161561	366117	3626	N			
29	164101	366119	2819	N			
30	163286	366122	1681	N			
31	163233	366134	5770	Y			
32	162128	366135	1589	N			
33	161560	366138	2998	N			
34	164103	366149	3307	Y			
35	162342	366150	2319	N			
36	164091	366153	2213	N			
37	163795	366155	2640	N			

38	164100	366161	2809	N			
39	162342	366165	2931	N			
40	163786	366167	2698	N			
41	164461	366168	3337	N			
42	164808	366170	3404	N			
43	164609	366174	2998	N			
44	163792	366176	1801	N			
45	164450	366193	2100	Y	2353	253	
46	165113	366203	1964	N			
47	163284	366209	2946	N			
48	163237	366211	3281	N			
49	164088	366219	2372	N			
50	164075	366220	2412	N	2774		362
51	164075	366221	1770	N			
52	163237	366228	3191	N			
53	164854	366229	1467	N			
54	161563	366238	1640	N			
55	162130	366240	2782	Y	3468	686	
56	162115	366241	1884	N			
57	164451	366245	3389	Y			
58	164084	366248	2503	N	2912		409
59	162347	366249	2367	N			
60	162341	366252	2647	N			
61	161567	366253	1711	N	3396		1685
62	163792	366254	1748	N			
63	164075	366258	1379	N			
64	161570	366261	3772	N			
65	161556	366263	2339	N			
66	164073	366264	1077	N			
67	163789	366270	2643	N			
68	163285	366271	2377	N			
69	163786	366283	1905	Y	2313	408	
70	162347	366285	2307	N	3849		1542
71	164455	366287	1163	N			
72	164174	366303	1621	N			
73	163234	366310	2651	N			
74	164460	366322	1964	N	2623		659
75	162139	366323	2424	N	2931		517
76	163791	366334	2083	N			
77	161556	366335	1933	N			
78	164456	366338	1324	N			
79	164455	366339	2402	N			
80	163799	366340	2238	N			
81	164100	366345	988	N			
82	161567	366348	500	N			

83	162136	366354	1760	Y	2286	526	
84	165122	366355	1046	N			
85	163285	366357	1483	N	3773		2290
86	164451	366365	2208	Y			
87	163286	366376	2661	N			
88	164076	366378	1158	N			
89	164458	366381	2237	N			
90	163795	366384	2432	N			
91	162117	366393	906	N			
92	163795	366401	1240	Y	2101	861	
93	165122	366403	325	N	1040		715
94	162115	366405	890	N			
95	164455	366411	2389	N	3318		929
96	162131	366414	2281	Y			
97	162139	366417	1692	N			
98	164455	366418	1459	Y			
99	164457	366432	2522	Y			
100	164451	366434	2213	Y	2753	540	
101	164098	366436	1590	N			
102	164800	366451	1229	N			
103	161554	366455	2605	N			
104	164087	366457	2067	N			
105	164447	366460	1721	N	3480		1759
106	164095	366470	1423	N			
107	164449	366472	1076	N			
108	163799	366476	1413	Y	2199	786	
109	162114	366478	3001	N			
110	164084	366485	1854	N	2474		620
111	164458	366488	1534	N			
112	164071	366493	1476	N			
113	164084	366499	1686	N			
114	162139	366505	1626	Y	2920	1294	
115	163288	366516	1062	N			
116	162117	366518	1906	Y			
117	162131	366521	1900	N			
118	161565	366522	1208	Y			
119	163784	366523	1953	Y			
120	163286	366527	2448	N			
121	164609	366531	1458	N			
122	164456	366532	2535	N	5285		2750
123	163795	366550	1548	N			
124	165259	366551	1884	N			
125	164447	366552	1871	N			
126	164610	366554	826	N			
127	164460	366558	1951	N			

128	164103	366562	2201	N			
129	164609	366568	1601	N			
130	164854	366575	2212	N			
131	165256	366579	431	N			
132	163234	366589	2407	N			
133	162128	366595	1589	Y			
134	164797	366608	2868	Y			
135	164459	366613	1284	N			
136	164617	366618	1237	N			
137	164620	366631	1671	N			
138	164076	366657	1273	N			
139	164620	366671	1671	N			
140	164797	366676	1390	N			
141	164100	366683	1055	Y	1475	420	
142	164610	366694	845	Y			
143	164087	366697	1072	N			
144	164812	366707	62	Y			
145	161554	366708	512	N			
146	161560	366714	1637	N			
147	161556	366715	1637	Y			
148	164449	366727	1438	N	2667		1229
149	163791	366728	911	N			
150	164614	366729	218	N			
151	162121	366739	1549	N			
152	164075	366741	1197	Y			
153	164800	366764	1662	N			
154	161561	366765	1662	N			
155	161565	366786	2007	Y	2451	1444	
156	163789	366794	455	N			
157	164841	366797	1334	N			
158	162341	366800	4513	N	9560		5047
159	164609	366814	399	Y			
160	165122	366821	990	N	1445		455
161	165259	366885	658	N			

APPENDIX B. TAIL ROTOR BLADES THAT RECEIVED UNSCHEDULED MAINTENANCE IN 1996

	BUREAU NUMBER	SERIAL NUMBER	TIME AT MAINTENANCE	CANN Y/N	TIME AT FAILURE	TIME BEFORE FAILURE CANN	TIME BEFORE FAILURE NON-CANN
1	164179	A23800011	1906	N	3023		1117
2	164445	A23800016	2503	Y			
3	163238	A23800028	4880	N	5626		746
4	164858	A23800035	1906	N	3521		1615
5	163791	A23800037	1015	N			
6	162990	A23800039	2006	N			
7	162341	A23800043	4413	N	5039		626
8	162121	A23800058	4150	Y	4878	728	
9	164098	A23800061	2158	N			
10	163238	A23800064	3969	N			
11	163286	A23800073	3011	N			
12	164101	A23800076	2852	Y			
13	162989	A23800083	2787	N			
14	162115	A23800089	4150	N			
15	163286	A23800098	3011	N			
16	163905	A23800099	3429	Y	4550		1121
17	164849	A23800100	2383	N			
18	162127	A23800101	3839	Y			
19	164097	A23800103	1424	N			
20	164445	A23800113	2361	N			
21	162989	A23800125	7819	N			
22	164080	A23800128	2457	N			
23	162125	A23800130	3276	N	4097		821
24	162330	A23800133	4980	N			
25	162120	A23800134	4032	N			
26	164801	A23800136	823	N	1148		325
27	164798	A23800141	1404	N			
28	162111	A23800168	1894	N			
29	163248	A23800183	4455	N			
30	164463	A23800189	1258	N			
31	164092	A23800196	2977	N			
32	163246	A23800197	5386	N			
33	162984	A23800203	1106	Y	1231	125	
34	164102	A23800213	1543	N	7964		6421
35	164615	A23800225	1652	N			
36	164098	A23800230	2158	N			
37	164076	A23800231	2939	Y			
38	161561	A23800234	3123	N			

39	161566	A23800237	5630	N			
40	162130	A23800239	3496	N	5941		2445
41	164445	A23800242	2503	N			
42	164086	A23800248	1906	N	3581		1675
43	164841	A23800249	2940	N			
44	162101	A23800259	3649	N			
45	163796	A23800260	1981	Y	2010	29	
46	162117	A23800269	6982	N			
47	164080	A23800275	2457	N	4081		1624
48	162114	A23800282	7212	N			
49	162332	A23800283	4332	N			
50	164179	A23800288	2702	N			
51	164850	A23800292	1393	N	1903		510
52	163241	A23800293	2692	Y			
53	162121	A23800296	4878	N	5479		601
54	162990	A23800298	2915	N	3357		442
55	164175	A23800301	2026	N			
56	162136	A23800305	346	N			
57	163243	A23800314	4666	Y	5598	932	
58	162128	A23800315	3810	N			
59	163799	A23800318	2398	N	5441		3043
60	162986	A23800320	6214	N			
61	162099	A23800321	3981	N			
62	163243	A23800323	4841	N			
63	164463	A23800328	2931	N			
64	162094	A23800337	6634	N	8293		1659
65	163237	A23800339	5479	N			
66	162982	A23800342	4462	N	5077		615
67	164459	A23800344	1803	N			
68	162127	A23800345	3839	N	5628		1789
69	163787	A23800364	2734	N			
70	162115	A23800368	2929	N			
71	163795	A23800377	3359	N			
72	164850	A23800378	2493	N	2509		16
73	162095	A23800379	7603	Y			
74	162133	A23800387	6997	N			
75	162332	A23800393	4332	N			
76	164455	A23800396	2390	Y	3226	836	
77	162987	A23800403	3830	Y	5206	1376	
78	164102	A23800406	1694	N	2852		1158
79	163235	A23800411	4823	Y	4880	57	
80	164618	A23800416	2885	N			
81	163242	A23800417	4665	N	5324		659
82	162109	A23800420	6079	N			
83	162988	A23800421	4623	N			

84	163790	A23800422	2766	N			
85	163798	A23800424	1598	N			
86	162114	A23800440	7495	Y	7603	108	
87	163792	A23800443	4035	N			
88	164858	A23800445	1906	N	3918		2012
89	164075	A23800461	2588	N	3411		823
90	164465	A23800472	3903	N	4085		182
91	164086	A23800480	1906	Y			
92	163246	A23800484	5386	N			
93	163910	A23800492	3305	N	4570		1265
94	163787	A23800500	2010	N			
95	164465	A23800541	2958	N			
96	164850	A23800544	1750	N	3128		1378
97	162134	A23800545	3805	N			
98	162111	A23800549	4611	N			
99	161562	A23800554	6490	N	8086		1596
100	162326	A23800557	1581	N			
101	163248	A23800570	2772	N			
102	163596	A23800573	1316	N			
103	163796	A23800591	1981	N			
104	162100	A23800592	6381	N	6520		139
105	163800	A23800600	1797	N	3303		1506
106	162989	A23800603	2286	Y	2364	78	
107	162133	A23800612	3359	N			
108	163799	A23800615	2271	N			
109	162125	A23800622	2042	Y	2457	415	
110	163905	A23800624	3756	N			
111	162333	A23800635	4665	N	7203		2538
112	164082	A23800636	2849	N			
113	164448	A23800640	3763	Y			
114	164448	A23800656	2157	N			
115	161561	A23800657	3123	N			
116	164103	A23800661	2913	Y	3139	226	
117	163247	A23800662	3256	N			
118	164448	A23800663	2309	N			
119	164619	A23800673	2141	N	3144		1003
120	163596	A23800684	4089	N			
121	162100	A23800685	6520	N	7441		921
122	161564	A23800686	5356	N	7105		1749
123	164457	A23800688	2141	N	2500		359
124	163288	A23800704	1909	N	2575		666
125	162123	A23800718	1611	Y	2411	800	
126	164092	A23800723	2977	N	4741		1764
127	162338	A23800726	8086	Y			
128	164104	A23800738	1909	N			

129	164459	A23800740	1803	N			
130	163285	A23800742	2500	N			
131	164618	A23800743	1351	Y	2683	1332	
132	164453	A23800744	2411	N			
133	162109	A23800753	2847	N			
134	163790	A23800754	2575	N			
135	163787	A23800755	2079	N			
136	164618	A23800763	435	N			
137	163798	A23800769	1598	N			
138	164617	A23800781	1154	N	2405		1251
139	162326	A23800786	474	N			
140	164617	A23800791	1154	N			
141	163795	A23800796	4574	N			
142	164104	A23800804	1909	N			
143	164617	A23800817	1154	N	1404		250
144	164176	A23800831	965	N			
145	165120	A23800834	1944	N			
146	164444	A23800839	2325	N			
147	164448	A23800840	2575	N			
148	163233	A23800845	2200	N			
149	162095	A23800846	7603	N			
150	164449	A23800850	2747	N			
151	163796	A23800853	981	N			
152	162115	A23800854	4150	N			
153	164082	A23800857	2849	N			
154	164454	A23800863	2131	N			
155	163910	A23800868	1816	N			
156	164850	A23800873	1089	N			
157	165120	A23800875	2013	N			
158	164103	A23800889	2241	N			
159	164448	A23800890	2287	Y	2431	144	
160	163242	A23800900	5324	N			
161	164103	A23800905	2696	N	7096		4400
162	164460	A23800912	2148	N			
163	162333	A23800915	1027	N			
164	163594	A23800917	4590	N			
165	162124	A23800923	2356	N			
166	164446	A23800927	2431	N	2727		296
167	162095	A23800935	3123	Y	3297	174	
168	162112	A23800937	6924	N			
169	164455	A23800938	2390	N			
170	163237	A23800941	5479	N	6392		913
171	162130	A23800948	5941	N			
172	163905	A23800951	1973	N	2696		723
173	162338	A23800973	2313	Y			

174	162112	A23800974	1922	N			
175	162102	A23800983	306	N			
176	164798	A23800991	1404	Y			
177	164069	A23800994	475	N			
178	164797	A23800998	1390	N			
179	162128	A23801005	3810	N			
180	164618	A23801006	1182	N			
181	164618	A23801007	1580	N			
182	164850	A23801013	2705	N			
183	162103	A23801014	1519	N			
184	164457	A23801017	2141	Y	2823	682	
185	162984	A23801020	1573	N			
186	163238	A23801022	4880	N			
187	164175	A23801028	3361	N	8218		4857
188	162134	A23801030	1458	Y			
189	164850	A23801031	1106	N			
190	162114	A23801032	7495	Y	8382	887	
191	164614	A23801038	1141	N			
192	161561	A23801042	3123	Y			
193	164797	A23801043	1390	N			
194	163905	A23801057	6377	N			
195	162099	A23801058	810	Y			
196	163249	A23801059	1330	N			
197	164459	A23801060	1163	Y	1435	272	
198	163284	A23801069	2913	Y	4081	1168	
199	164798	A23801070	1404	N			
200	163800	A23801083	1797	N			
201	162338	A23801094	8086	Y	8857	771	
202	164801	A23801101	1148	N	2308		1160
203	164858	A23801112	1906	Y			
204	162341	A23801114	1335	Y			
205	163910	A23801116	3305	N	4301		996
206	164811	A23801133	1820	N			
207	164858	A23801137	1906	Y	5878	3972	
208	164841	A23801154	1202	N			
209	164842	A23801156	895	N			
210	164816	A23801157	589	N			
211	164080	A23801161	2457	N	3884		1427
212	164846	A23801178	243	N			
213	165121	A23801180	959	N			
214	165121	A23801181	1073	N			
215	162984	A23801183	406	Y	2337	1931	
216	162986	A23801195	6214	N			
217	162109	A23801210	6392	N			
218	161566	A23801234	5629	N	6221		592

219	161569	A23801235	5403	N		
220	164615	A23801238	1652	N		
221	165114	A23801239	304	N		
222	162338	A23801242	8086	Y		
223	165114	A23801244	233	N		
224	162130	A23801246	5941	N		
225	165114	A23801251	233	N	936	703
226	164842	A23801254	895	N		
227	163243	A23801259	4841	N		
228	164849	A23801267	2383	N		
229	164082	A27200872	2679	N		
230	164842	A28301156	895	N		
231	164454	A32800128	2457	N		
232	164850	A39803965	2926	N		
233	165114	A39808940	233	N		

APPENDIX C. AUXILIARY POWER ELECTRONIC CONTROL UNITS THAT RECEIVED UNSCHEDULED MAINTENANCE IN 1996

	BUREAU NUMBER	SERIAL NUMBER	TIME at MAINTENANCE	CANN Y/N	TIME AT FAILURE	TIME BEFORE FAILURE CANN	TIME BEFORE FAILURE NON-CANN
1	162131	73750239	5573	N			
2	163907	73750063	3165	N			
3	162982	73750377	4697	N	5009		312
4	163286	73750495	3076	N			
5	163906	73750602	4064	N	5504		1440
6	163235	73750642	5009	N			
7	164082	73750661	2848	Y			
8	165107	73750691	602	N			
9	162975	73750704	3975	N			
10	163906	73750756	4064	Y	5504	1440	
11	163259	73750757	2438	N			
12	162124	73750778	4892	N			
13	164809	73750787	1498	N			
14	163598	73750819	4424	N			
15	162982	73750829	4697	N			
16	163905	73750832	3429	N	4579		1150
17	162344	73750833	6120	N			
18	163797	73750881	1912	Y			
19	164099	75840075	2476	Y			
20	164081	75840152	2429	N			
21	164466	75840436	3030	N			
22	162136	75840495	6301	Y	6724	423	
23	162095	75840514	4258	N	7603		3345
24	162333	75840544	6554	N			
25	162136	75840678	6402	Y	7264	862	
26	164463	75840683	3359	N			
27	163593	75840740	4454	Y	5077	623	
28	164849	75840752	2664	N			
29	161554	75840755	570	N			
30	162131	75840880	5577	Y			
31	163797	75840902	1913	N	2767		854
32	162099	75840913	7305	Y	7332	27	
33	162133	75840924	6514	N			
34	164102	75840987	1141	Y			
35	161567	75841109	5641	N	8239		2595
36	162115	75841169	4258	Y	5617	1359	
37	161556	75841250	3601	Y	4008	407	

38	162102	75841222	7006	N			
39	163266	75841252	2454	N			
40	163261	75841257	2366	N			
41	162117	75841282	6816	N			
42	173790	75841437	1912	N	2736		824
43	163284	75841548	2704	N			
44	164445	75841560	2283	N			
45	165095	75841566	1501	N			
46	164081	75841578	2429	N			
47	162133	75841580	6444	N			
48	163233	75841683	5077	N			
49	162104	75841715	1103	N	5494		4391
50	164447	75841813	2480	Y	2977	497	
51	162095	75841820	7603	N			
52	164101	75841935	2540	Y			
53	164812	75842007	1317	N			
54	164801	75842015	1103	N			
55	164813	75842036	1199	N			
56	164455	75842040	2390	Y			
57	164450	75842058	2405	N			
58	162985	75842509	4350	N			
59	162123	75842537	6381	N			
60	163794	75842547	28774	Y			
61	163795	75842576	3345	N			

APPENDIX D. T700-GE-401C CANNIBALIZED 1995-1999

	Bureau Number	Serial Number	Engine Hrs at Cannibalization
1	162100	366321	1818
2	163791	366023	1880
3	163791	366155	2516
4	164102	366420	846
5	164102	366143	846
6	162128	366135	2921
7	162128	366595	1589
8	162130	366240	2782
9	164455	366418	1459
10	164455	366084	2462
11	164461	366786	2007
12	164451	366365	2208
13	164451	366434	2213
14	164451	366245	3389
15	164451	366505	1626
16	163784	366523	1953
17	163784	366097	2556
18	164450	366401	1240
19	164450	366193	2100
20	163786	366476	1413
21	163786	366283	1905
22	162136	366354	1760
23	162136	366814	398
24	163247	236682	676
25	163247	366707	676
26	164610	366694	845
27	164610	388201	2085
28	164071	366067	3794
29	164075	366741	1197
30	164798	366608	2869
31	161559	366715	1641
32	164610	366201	2907
33	164610	366775	2907
34	164072	366642	2026
35	164457	366723	889
36	164457	366416	2570
37	164810	366527	2938
38	164810	366220	2774
39	163596	366800	1407

40	163596	366646	1407
41	165258	366871	1101
42	165258	366609	1100
43	162114	366683	1055
44	162114	366362	2740
45	162330	366216	3276
46	161565	366668	1657
47	164798	366750	1849
48	164798	366443	1849
49	162327	366147	2250
50	162327	366629	2928
51	161565	366279	4809
52	161565	366230	4809
53	161554	366066	3980
54	161554	366477	1854
55	162127	366072	1904
56	162127	366350	1873
57	162349	366839	960
58	162349	366700	1043
59	164446	366308	202
60	164446	366219	202
61	161566	366520	2276
62	164614	366156	3077
63	164614	366143	1789
64	164446	366718	2732
65	164101	366149	2655
66	161556	366532	5285
67	164465	366581	3277
68	164465	366016	2341
69	162099	366240	2783
70	164088	366582	1251
71	163285	366778	1462
72	163285	366315	1462
73	161556	366114	3297
74	161556	366064	3515
75	164445	366613	1518
76	163285	366733	1139
77	164609	366026	4840
78	162988	366692	2067
79	162988	366745	2067
80	163906	366266	3586
81	162124	366433	3706
82	165258	366300	1663

83	163906	366853	675
84	163906	366266	3586
85	164450	366119	1276
86	164450	366034	1276
87	164610	366183	1349
88	164610	366345	1118
89	164450	366193	2100
90	164450	366430	3450
91	162124	366362	2970
92	162124	366773	1808
93	162327	366800	1711
94	162327	366727	2667
95	164453	366831	1811
96	164610	366790	2051
97	163287	366468	1249
98	163287	366357	1483
99	162341	366853	984
100	162341	366693	1954
101	162341	366460	3480
102	162330	366106	2630
103	162330	366669	3553
104	164081	366380	3460
105	164081	366229	2791
106	162341	366615	7529
107	162341	366693	7529
108	164798	366331	2609
109	163284	366609	3302
110	163284	366338	3150
111	164072	366485	2474
112	164072	366522	1880
113	162126	366665	5807
114	162126	366200	4143
115	164449	366308	3321
116	164449	366485	2474
117	164615	366469	3593
118	164615	366013	4964
119	162104	366179	3869
120	162104	366886	1278
121	163794	366448	2497
122	164803	366074	2126
123	164449	366191	2797
124	164449	366308	3321
125	161569	366853	985

126	164443	366024	1564
127	164443	366661	2209
128	164450	366018	4395
129	164450	366449	3042
130	164450	366026	5368
131	164450	366139	4233
132	161568	366542	2845
133	161568	366671	2845
134	164841	366583	3246

APPENDIX E. TAIL ROTOR BLADES CANNIBALIZED 1995-1999

	Bureau Number	Serial Number	Flight Hrs at Cannibalization
1	164178	A23801023	2822
2	162125	A23800720	1963
3	162125	A23800622	2702
4	163797	A23800754	2074
5	164102	A28300123	1141
6	164102	A28300213	1141
7	162105	A23800488	4121
8	162105	A23800596	0
9	164457	A23800124	2057
10	164457	A23800688	2057
11	164457	A23500162	2057
12	164457	A23801005	2057
13	162123	A23800995	1927
14	162123	A23801002	4309
15	162123	A23800426	4309
16	162123	A23800351	3386
17	164081	A23800275	2429
18	164081	A23800734	2429
19	163784	A23800641	2264
20	163784	A23801061	2264
21	163784	A23800110	2664
22	163784	A23801018	2664
23	163784	A23800312	2664
24	162139	A23800622	2764
25	162139	A23800773	1678
26	164102	A23800776	1855
27	164102	A23800759	1141
28	164100	A23800776	1855
29	164100	A2380035	2617
30	164099	A23800997	2783
31	164099	A23800396	2022
32	164099	A23800294	1811
33	162136	A23800301	2026
34	162136	A23800305	346
35	164086	A23800480	1906
36	164086	A23800248	1906
37	164797	A23801043	1390
38	164797	A23801047	1390
39	164797	A23801060	1390

40	164797	A23800998	1390
41	161562	A23801094	6490
42	161562	A23800726	6490
43	162338	A23801242	8086
44	162338	A23800554	8086
45	162338	A23800726	8086
46	162338	A23801094	8086
47	164455	A23800396	2390
48	164804	A23800113	4158
49	164804	A23800282	2776
50	164071	A23800314	4666
51	164071	A23800688	2337
52	162128	A23801005	3810
53	162128	A23800570	3810
54	162128	A23801032	3810
55	162128	A23800315	3810
56	164082	A23800857	2849
57	163241	A23800293	2692
58	163241	A23800403	3830
59	162112	A23801210	6924
60	162112	A23800937	6924
61	164448	A23800890	2287
62	164448	A23801180	2287
63	162127	A23800101	3839
64	162127	A23800345	3839
65	164101	A23800406	2852
66	163238	A23800411	4880
67	163238	A23800028	4880
68	162338	A23800973	2313
69	161561	A23800935	3123
70	161561	A23800657	3123
71	161561	A23800234	3123
72	161561	A23801042	3123
73	162984	A23801183	406
74	162984	A23800203	1106
75	162095	A23800379	7603
76	162095	A23800234	3123
77	162989	A23800603	2286
78	163284	A23800661	2913
79	163284	A23801069	2913
80	162095	A23800846	7603
81	162095	A23800440	2411
82	162095	A23800379	7603
83	161554	A23801030	1458
84	164618	A23800743	1351

85	164618	A23800416	2285
86	164071	A23801183	2337
87	164071	A23801013	2337
88	164446	A23800890	2431
89	164446	A23800927	2431
90	164448	A23800640	3763
91	164448	A23800656	2037
92	161566	A23800237	5630
93	161566	A23801234	5629
94	161569	A23800983	5403
95	161569	A23801235	5403
96	163796	A23800591	1981
97	163796	A23800260	1981
98	163796	A23800500	1981
99	163796	A23800853	1981
100	164097	A23800103	1424
101	164619	A23801017	2141
102	164619	A23800673	2141
103	162982	A23801059	1330
104	162982	A23800342	4462
105	164618	A23801006	1182
106	164618	A23800763	435
107	162115	A23800058	4150
108	162115	A23800854	4150
109	162115	A23800368	2929
110	162115	A23800089	4150
111	162111	A23800549	4611
112	162111	A23800168	1894
113	164453	A23800744	2411
114	164453	A23800440	2411
115	164454	A23800863	2131
116	164454	A32800128	2457
117	164798	A23800991	1404
118	164798	A23800141	1404
119	164798	A23800817	1404
120	164798	A23801070	1404
121	164445	A23800016	2503
122	164445	A23800242	2503
123	164619	A23800756	2307
124	164619	A23800162	2307
125	164619	A23800697	2307
126	164619	A23800756	2307
127	164619	A23801379	2307
128	164074	A23801124	3601
129	164074	A23806850	3601

130	164074	A23800737	3601
131	164074	A23801048	3601
132	162099	A23801058	7683
133	162099	A23800672	1115
134	162136	A23801021	6402
135	162136	A23801064	6402
136	162099	A23800944	1944
137	162099	A23800456	3917
138	163237	A23807071	5938
139	163237	A23800178	5938
140	164095	A23800272	2887
141	164095	A23800268	2887
142	164095	A23800258	2887
143	164095	A23801338	2887
144	162114	A23800001	7747
145	162114	A23801032	7747
146	164095	A23800337	2887
147	162120	A23801122	7018
148	164176	A23801258	1373
149	164176	A23800754	2074
150	165154	A23801277	89
151	164449	A23800889	2768
152	164101	A23801306	2852
153	162122	A23800957	3778
154	162122	A23801028	1595
155	162327	A23801114	7562
156	162327	A23800628	7562
157	163249	A23800231	6340
158	163249	A23800622	6340
159	163249	A23800689	6340
160	164070	A23800148	1856
161	164070	A23801313	1856
162	164449	A23800871	2768
163	164449	A23800880	2768
164	164614	A23800971	2535
165	164614	A23800292	2535
166	164086	A23800066	1906
167	162348	A23801161	6392
168	162348	A23800847	6392
169	162348	A23800941	6392
170	164086	A23800011	1906
171	164445	A23800608	2581
172	164445	A23800682	2581
173	164817	A23800450	1291
174	164817	A23800318	1291

175	163249	A23801265	6340
176	163249	A23801115	6340
177	162335	A23800372	7526
178	162335	A23800213	1446
179	164085	A23800162	3725
180	164085	A23800250	3725
181	164070	A23800412	1856
182	164070	A23800879	1856
183	162122	A23800957	8103
184	162109	A23801161	7772
185	162109	A23800969	6392
186	163233	A23800342	5795
187	163233	A23801265	5795
188	163233	A23800751	5795
189	163233	A23801115	5795
190	162335	A23801058	811
191	162335	A23800603	2364
192	164084	A23800473	6116
193	164799	A23800458	2499
194	164799	A23801066	2499
195	162344	A23801002	6513
196	162344	A23800844	6724
197	164803	A23800777	2595
198	164803	A23800805	2595
199	162124	A23800924	5627
200	162124	A23800022	5627
201	164803	A23800078	2595
202	164620	A23800671	2665
203	164620	A23801121	2665
204	164854	A23801097	3401
205	164854	A39810128	3401
206	164074	A23800752	3601
207	164074	A23200240	3601
208	164074	A23800654	3719
209	164074	A23801234	3601
210	164074	A23800268	3601
211	164450	A23800916	2745
212	164450	A23800790	2978
213	164100	A23801139	2678
214	164100	A23802658	2678
215	163237	A23800957	5938
216	163237	A23800647	5938
217	164074	A23801338	3601
218	164074	A23800752	3601
219	162326	A23800786	1611

220	162326	A23801313	1611
221	164074	A23800654	3719
222	164074	A23801338	3601
223	164074	A23806850	3601
224	164074	A23801234	3601
225	164074	A23800636	3601
226	164074	A23801125	3601
227	164074	A23800654	3601
228	164074	A23801125	3601
229	164074	A23800654	3601
230	162124	A23800130	5627
231	162124	A23800272	4346
232	164074	A23801125	3601
233	162096	A23800053	5016
234	162096	A23800049	3658
235	164074	A23801417	3601
236	164074	A23801421	3601
237	164074	A23801048	3601
238	164074	A23800752	3601
239	164074	A23801348	3601
240	164458	A23800473	6116
241	164458	A23800048	1820
242	162330	A23800764	8364
243	162330	A23801479	8364
244	163287	A23801060	2926
245	163287	A23800618	2926
246	163287	A23800999	2926
247	164089	A23800996	3032
248	162109	A23800891	8209
249	162109	A23801011	8209
250	164074	A23800268	3601
251	164074	A23800971	3601
252	164074	A23801094	3601
253	163284	A23801069	4101
254	163284	A23800292	4101
255	164074	A23800752	3601
256	162121	A23800318	6335
257	162121	A23800345	6335
258	162121	A23800587	6051
259	163788	A23801146	3439
260	163788	A23800253	3439
261	162330	A23801479	8364
262	162330	A23800909	8364
263	162106	A23801250	8103
264	162106	A23801109	8103

APPENDIX F. AUXILIARY POWER ELECTRONIC CONTROL UNITS CANNIBALIZED 1995-1999

	Bureau Number	Serial Number	Flight Hrs at Cannibalization
1	164449	75842623	2524
2	164099	75840075	2476
3	164099	75841176	2476
4	164447	75841813	2480
5	162131	75840880	5577
6	162131	73750239	5573
7	164455	75842044	2390
8	161556	75841250	3601
9	164797	75842415	1390
10	164082	73750661	2848
11	162136	75840495	6301
12	163906	73750756	4064
13	162095	75841169	4258
14	163593	75840740	4454
15	163797	73750881	1912
16	164101	75841935	2540
17	162348	75840028	6162
18	163794	75842547	2874
19	164100	75680021	2092
20	162985	75841260	4350
21	164102	75840987	1141
22	164466	75840436	3030
23	164074	75841250	2880
24	161563	75840688	6024
25	162114	73750110	7747
26	163249	75842574	6340
27	164801	756879674	1590
28	164095	75842623	2887
29	164095	75841099	3210
30	164074	75841250	3601
31	163248	75840985	4925
32	164102	73750732	2257
33	162980	75841858	5832
34	162095	75840346	8177
35	163237	73750381	5938
36	162121	75840712	5617
37	162139	75842015	5959
38	162096	75840913	7305
39	162095	73750187	8873
40	161553	75840417	7188

41	162328	75841811	7243
42	164098	75841250	3254
43	164098	73750689	2880
44	163906	75840447	2052
45	164080	75841778	3501
46	164450	7584475	2978
47	164074	7581778	2333
48	162345	73750646	6659
49	164074	75841508	3601
50	162096	73750107	7305
51	163285	75842482	2870
52	162101	75841109	8238
53	162335	75840063	8558
54	162095	73750187	9304
55	162989	75841049	6520
56	163245	75841560	5794
57	164615	75840085	2882
58	164443	75842057	1944
59	164101	75842472	3659
60	162106	73750187	8103
61	164444	73750405	3603
62	164808	75840415	3783
63	163234	7584262	8671

LIST OF REFERENCES

1. Chief of Naval Operations, *Naval Aviation Maintenance Program, OPNAVINST 4790.2G Volume II,* para 12.1.11, 1 February 1998.

2. Naval Aviation Maintenance Support Office Report 4790.A7040-01. *3M Aviation Maintenance Summary,* 21 October 1999.

3. Naval Air Systems Command, *Aviation Maintenance Manager's Guide*, Section 9, [http://greenshirt.nalda.navy.mil/mngr_guide/toc9.htm]

4. Donnelly, J., " Top Carrier Warplanes Run Low on Parts," *Defense Week.* 18 January, 1999.

5. Deputy Secretary of Defense, *Program Budget Decision 423*, p5, Government Printing Office, Washington D.C., 1 December 1999.

6. Rand Institution, *Estimating Aircraft Recoverable Spares Requirements with Cannibalization of Designated Items*, By D.P. Graver, p. 9, 1993.

7. Under Secretary of Defense Comptroller, " Military Composite Standard Pay and Reimbursements Rates" [http://www.dtic.mil//comptroller/rates/2000-k2pdf.]. October 1999.

8. Naval Aviation Maintenance Support Office Report 4790.A8855-10, *Cannibalization Analysis Summary,* 21 October 1999.

9. Commander Naval Air Force Atlantic, Commander Naval Air Force Pacific, *Aviation Maintenance and Supply Readiness Cannibalization Issue 62,* By J. Rosa, p. 2, 26 August 1999.

10. Naval Air Systems Command, *Maintenance Trade Cost Guidebook,* Appendix E p.3, NAVAIR 4.2, 17 July 1997.

11. Naval Supply Command, Logistics Management Decision Support System, [https://nast20.nalda.navy.mil/cgi-bin/ssm_mfhbf_submit.pl]

12. Commander Naval Safety Center, radio message 128-076 to AIG 6940, Subject: 2000 Engine Cost Data for Aviation Mishap Reporting, 141401Z Mar 2000.

THIS PAGE INTENTIONALLY LEFT BLANK

INTIAL DISTRIBUTION LIST

Defense Technical Information Center 2
8725 John J. Kingman Rd., STE 0944
Ft. Belvoir, Virginia 22060-6218

Dudley Knox Library 2
Naval Postgraduate School
411 Dyer Rd.
Monterey, California 93943-5101

Multi-Mission Helicopter Program (PMA-299) 1
Naval Air Systems Command
47123 Buse Road Unit Moffett Building
Patuxent River, Maryland 20650-1547

Naval Support Activity 1
H-60 Integrated Weapons Support Team
700 Robins Avenue
Philadelphia, Pennsylvania 19111-5098

Donald Eaton Code SM/ET 1
Department of Systems Management
Naval Postgraduate School
Monterey, Ca 93934-5000

Dr. Shu S. Liao Code SM/LC 1
Department of Systems Management
Naval Postgraduate School
Monterey, Ca 93934-5000

CDR Danny E. Kowalski Pers9D 1
Navy Personnel Command
5720 Integrity Drive
Millington, Tennessee 38055